DATA ANALYSIS REPORT

Road Traffic in Gyeongsangnam-do Analyzed Through Network Theory

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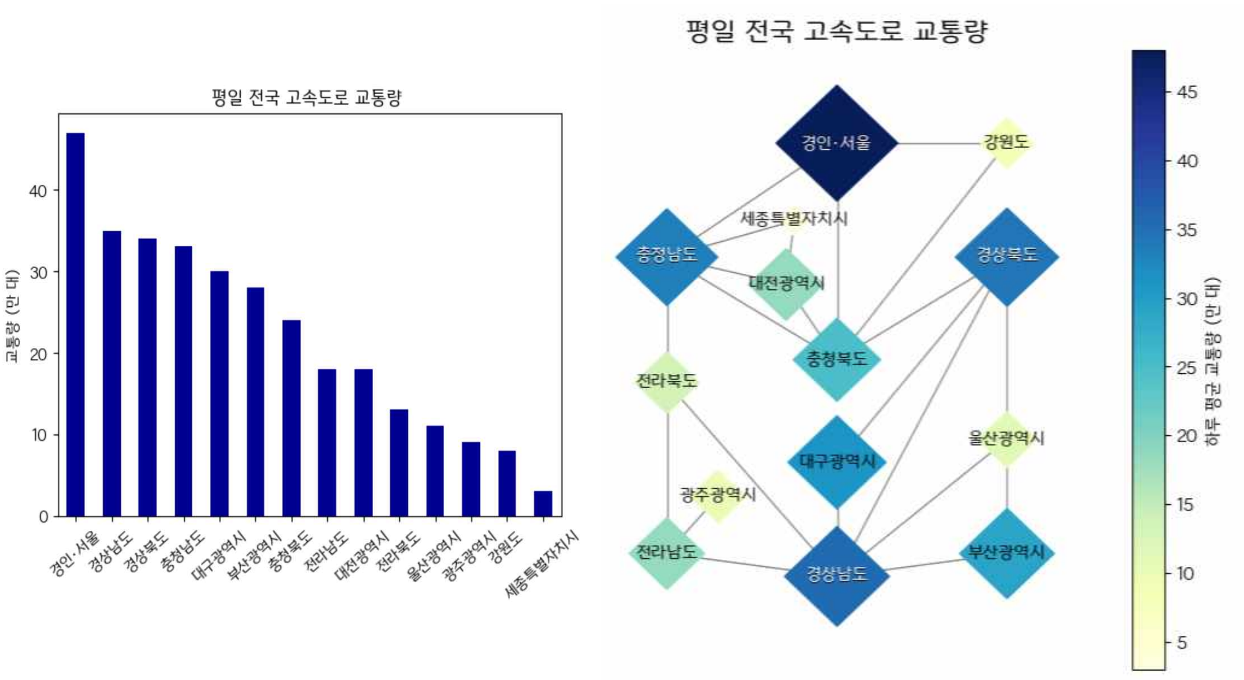
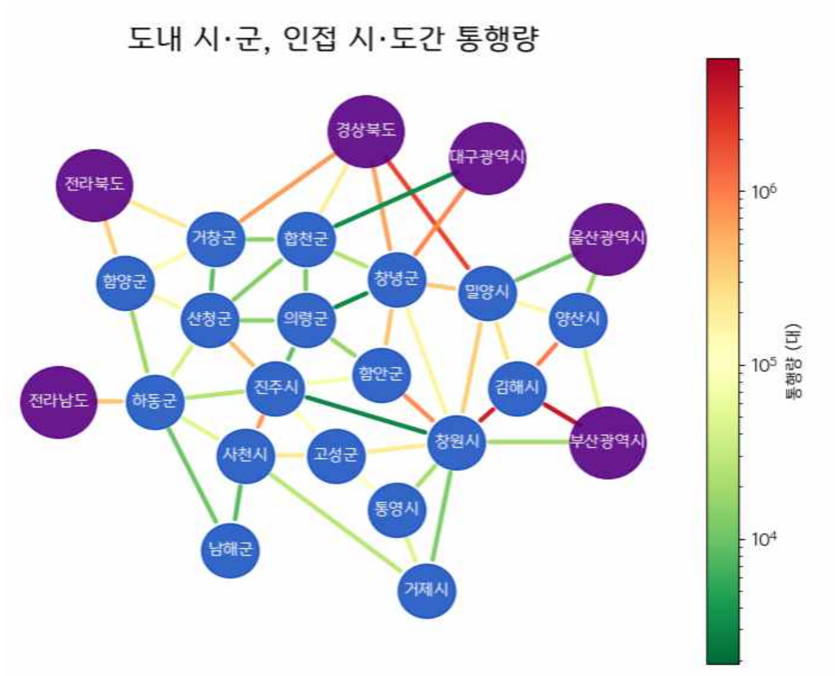
This analysis begins by recognizing that Gyeongsangnam-do[1] comprises 18 cities and counties. The province is conceptualized as a network of 18 nodes, each representing a city or county, and is analyzed using network theory[2][3]. Building on this framework, I also considered South Korea as a network composed of 17 metropolitan municipalities. Since Gyeongsangnam-do is the central focus of this analysis, I structured the study in a layered manner: beginning with the national-level network, then narrowing the scope to the network of cities and counties in Gyeongsangbuk-do and its adjacent metropolitan areas, and finally concentrating on the internal network of Gyeongsangbuk-do. This approach allows me to progressively narrow the analytical lens while deepening the level of insight throughout the discussion. In these networks, I considered road traffic data—such as segment traffic volumes and travel speeds—as effective indicators of node characteristics and inter-node connectivity. Accordingly, I utilized datasets provided by the Gyeongnam Big Data Hub Platform[4], the Highway Public Data Portal operated by the Korea Expressway Corporation[5] , and the Traffic Volume Information System managed by the Ministry of Land, Infrastructure and Transport and the Korea Institute of Civil Engineering and Building Technology[6]. In addition, to ensure a rational analysis and interpretation of the data, I consulted a variety of supplementary datasets and scholarly literature. These references are cited throughout the main text and detailed in the footnotes. Since this study involves network analysis, I employed not only the widely used visualization library Matplotlib[7] for general plotting, but also NetworkX[8], a specialized tool designed for visualizing and analyzing network structures.

To begin, I calculated the average weekday highway traffic volume between South Korea's 17 metropolitan municipalities and visualized the results as shown in [Figure 1]. Specifically, due to the extensive nature of the "traffic volume between tollgates" dataset provided by the Korea Expressway Corporation, I limited the scope of analysis to four weekdays in June 2024 (the 4th, 12th, 20th, and 24th). I used the total traffic volume without distinguishing between the six vehicle types. This dataset includes columns such as "departure tollgate name," "arrival tollgate name," and "total traffic volume toward arrival." To determine the origin and destination regions at both the metropolitan and district levels, I merged this data with the "status of tollgates by route" dataset, which contains address information for each tollgate. In cases where tollgate names did not match across the two datasets, I supplemented the missing information by manually entering addresses based on the Wikipedia entry "List of highway tollgates in South Korea."[9] Using the addresses of departure and arrival tollgates along with the total traffic volume toward each destination, I constructed an adjacency matrix representing inter-municipality traffic volumes. I excluded diagonal elements that represent internal traffic within each municipality and calculated the sum of each row to derive the average weekday highway traffic volume per metropolitan municipality. These results were visualized in both bar graph and network formats, as shown in [Figure 1]. In the network visualization, adjacent municipalities were connected by edges[10], and traffic volume was reflected in the size and color of each node. Gyeongsangnam-do, notably, had the highest number of neighboring nodes and recorded the second-highest traffic volume after the Seoul Capital Area—averaging approximately 350,000 vehicles per day. Alongside Gyeongsangbuk-do (340,000) and Chungcheongnam-do (330,000), it plays a pivotal role as a transportation hub in the non-capital regions.

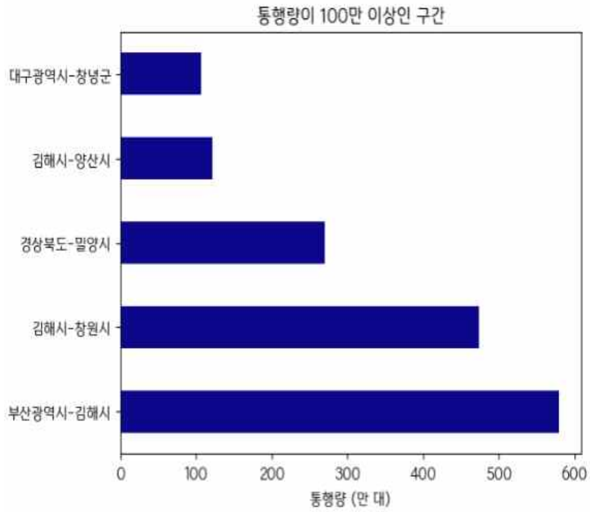


[Figure 1] (1) Average weekday traffic volume between adjacent metropolitan municipalities in South Korea. In accordance with the analytical intent, internal traffic within each municipality was excluded from the aggregation. (2) Network visualization of inter-municipality traffic. Pairs of neighboring municipalities are connected by edges, and traffic volume is represented through the size and color of each node.

Next, I constructed a network of Gyeongsangnam-do's cities and counties along with its neighboring metropolitan municipalities, as shown in [Figure 2]. To do this, I first referred to the "Road Status by City/County in Gyeongsangnam-do"[11] dataset provided by the Gyeongnam Big Data Hub Platform. This revealed that the province contains five types of roads: expressways, national highways, provincial roads, city roads, and county roads. Notably, Gimhae-si, Namhae-gun, and Uiryeong-gun do not have expressways. Recognizing the limitations of relying solely on expressway data—as in the previous analysis—I instead used the "Traffic Volume by Road Type" dataset from the Traffic Volume Information System, which provides traffic data for expressways, national highways, and provincial roads. (Data for city and county roads was unavailable and thus not reflected in the network.) The Traffic Volume Information System requires users to specify both the road type and route number to retrieve traffic volumes for specific segments. Therefore, I first identified the types and route numbers of roads within the province. For this, I consulted the "Road Status" datasets for Geochang-gun, Yangsan-si, and Changwon-si available on the Gyeongnam Big Data Hub Platform. For the remaining 15 municipalities, whose road data was not available on the platform, I supplemented the information using the Wikipedia entry “Road Routes in Gyeongsangnam-do.” The “Traffic Volume by Road Type” dataset aggregates traffic volumes at survey points without regard to direction, resulting in a non-directional network. As in the previous analysis, I used total traffic volume figures without distinguishing between vehicle types. To align with the study’s goal of examining connectivity between metropolitan and local governments, I only included traffic volumes for segments where the addresses of the two endpoints belonged to different administrative units (e.g., different cities, counties, or provinces). [Figure 3] presents a graph highlighting segments with traffic volumes exceeding one million vehicles. Edges connecting nodes are shown in red to indicate high traffic intensity. The segments between Busan Metropolitan City and Gimhae-si, and between Gimhae-si and Changwon-si, show exceptionally high traffic volumes of 5.8 million and 4.74 million vehicles, respectively.

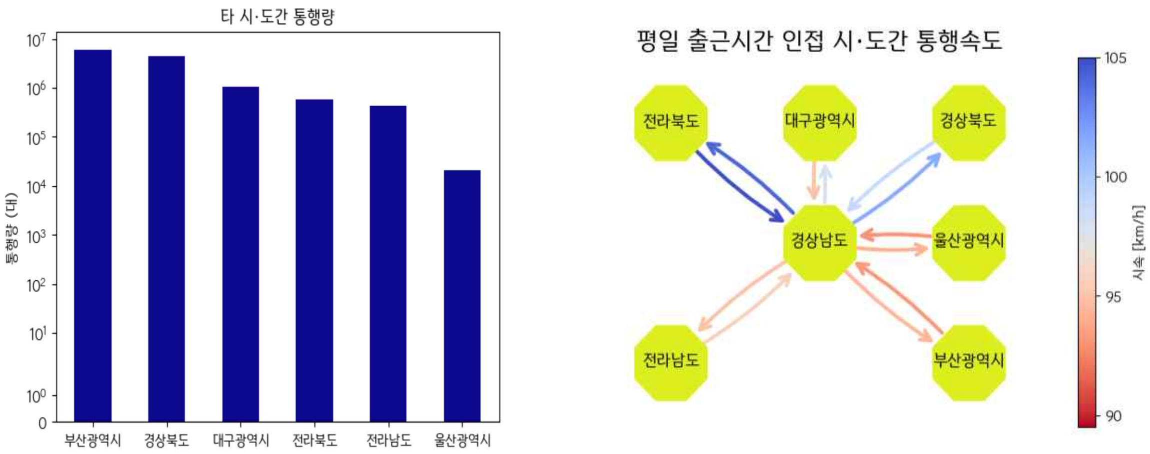


[Figure 2] A network composed of nodes representing the cities and counties of Gyeongsangnam-do and its neighboring metropolitan municipalities. The edges connecting the nodes are weighted by the traffic volume of each segment.



[Figure 3] Traffic volumes exceeding one million vehicles in the network connecting Gyeongsangnam-do and its neighboring metropolitan municipalities. Segments with such high traffic are represented by red edges between nodes.

The aggregated traffic volume between Gyeongsangnam-do and its neighboring metropolitan municipalities is presented in [Figure 4-1]. As partially observed in [Figure 3], the highest traffic volumes are with Busan Metropolitan City, Gyeongsangbuk-do, and Daegu Metropolitan City, followed by Jeollabuk-do, Jeollanam-do, and Ulsan Metropolitan City. [Figure 4-2] illustrates a network in which the nodes represent metropolitan municipalities adjacent to Gyeongsangbuk-do, and the edges are weighted by the average highway travel speed at 7 a.m. on weekdays. To calculate this morning commute speed, I first used the “Weather Information by Rest Area” open API provided by the Highway Public Data Portal[12]. This API allows queries by date and time, and returns data including rest area name, address, precipitation, and snowfall levels. Using this, I confirmed that there was no rainfall on the four selected weekdays in June 2024. Subsequently, I retrieved hourly travel speed data from the “Segment Travel Speed_1 Hour_1 Day” dataset on the same portal. Based on the observation that average travel speed tends to reach its lowest point at 7 a.m., I adopted this time as a proxy for weekday morning congestion. The dataset includes fields such as “Conzone ID,” “Aggregation Time,” and “Average Speed.” To determine which regions each segment connects, I merged this data with the “Conzone” dataset (which specifies start and end nodes)[13], the “Node Distance Information by Route,” and the tollgate address data used earlier. In cases where segment locations remained unclear, I referred to the ROADPLUS highway traffic map provided by the Korea Expressway Corporation. By constructing a network using segment-level average speeds as edge weights and comparing it with traffic volume data, I was able to assess the performance of road infrastructure and identify segments in need of improvement ([Figure 4]). While high traffic volumes typically correlate with reduced travel speeds, an interesting exception was observed in the corridor connecting to Gyeongsangbuk-do, which maintained relatively high speeds despite heavy traffic. Conversely, the corridor leading to Ulsan Metropolitan City exhibited significant congestion despite lower traffic volumes. This suggests that targeted investigation into the causes of congestion in this segment is necessary to improve traffic flow.

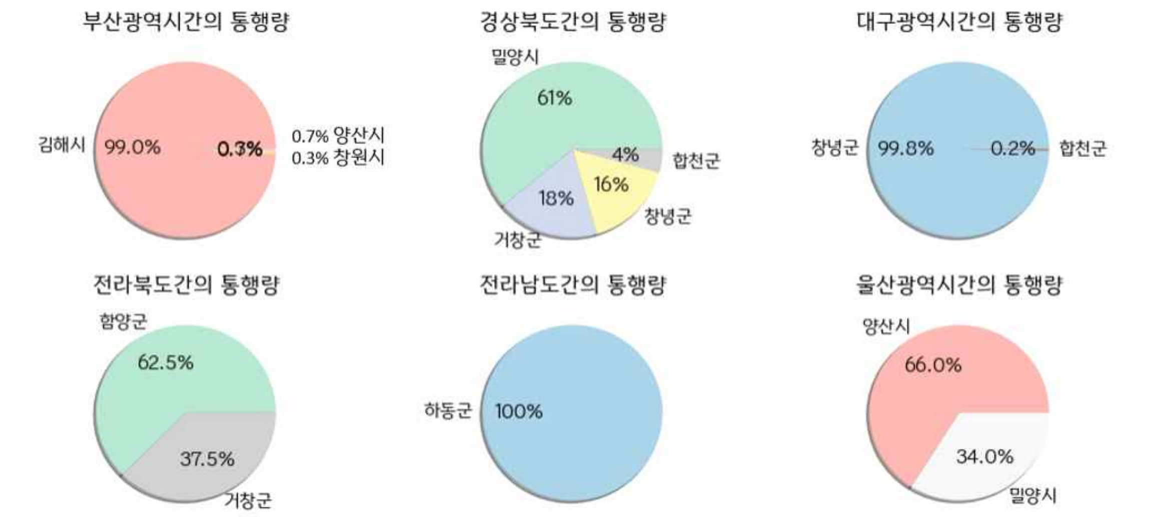


[Figure 4] (1) Traffic volume between Gyeongsangnam-do and its neighboring metropolitan municipalities. (2) Average highway travel speed at 7 a.m. on weekdays between Gyeongsangnam-do and adjacent regions. To prevent rainfall from skewing the speed data, only dates with no morning precipitation were selected using the “Weather Information by Rest Area” dataset provided by the Korea Expressway Corporation.

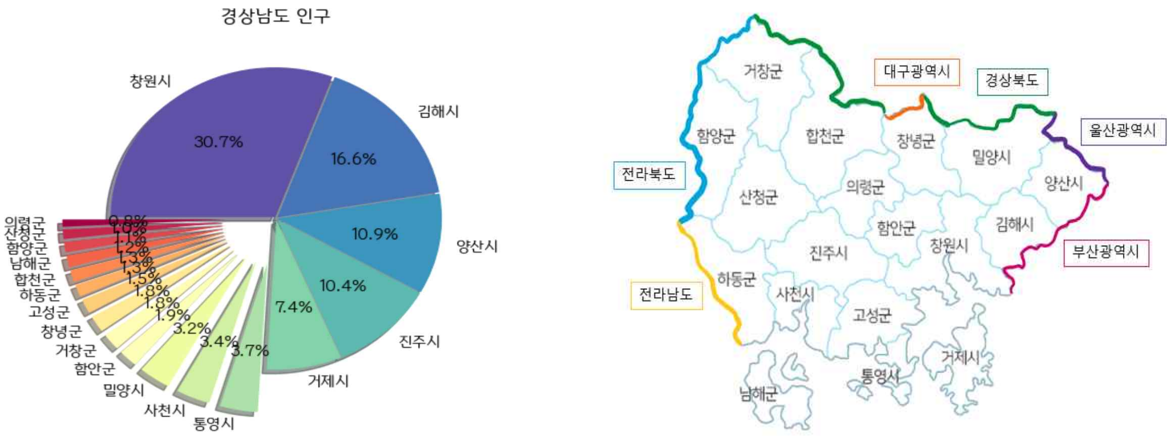
Following the observation that traffic between Gyeongsangnam-do and Busan Metropolitan City is particularly concentrated through Gimhae-si—one of three available routes—I examined the degree of balance among the different routes connecting Gyeongsangnam-do to its six neighboring metropolitan municipalities. As shown in [Figure 5], the overall distribution appears to be notably imbalanced.
For instance, traffic to Jeollanam-do is entirely concentrated on National Route 59, which passes through Hadong-gun, resulting in a calculated share of 100%. Despite the availability of multiple routes to Busan and Daegu Metropolitan Cities, over 99% of traffic is concentrated on a single route in each case. Similarly, for Jeollabuk-do and Ulsan Metropolitan City, one of the two available routes carries more than 60% of the traffic load. To investigate the causes of this imbalance, I referred to population distribution data and regional maps of Gyeongsangnam-do ([Figure 6]). The population data is based on the “Gyeongsangnam-do Population” dataset from the Gyeongnam Big Data Hub Platform, while the map was obtained from the “Status by City/County” section of the Gyeongsangnam-do official website, with added labels for neighboring metropolitan municipalities and their boundaries. By comparing these two sources with the previous traffic findings, I identified three primary factors likely contributing to the observed imbalance in road traffic: A particularly close relationship between Gyeongsangnam-do and Busan Metropolitan City, Population concentration in areas adjacent to Busan, Geographic constraints.

The first factor, as clearly illustrated in [Figure 3], leads directly to the second: the population concentration in Changwon, Gimhae, and Yangsan. Specifically, approximately 60% of Gyeongsangnam-do’s population resides in this region, with half of that concentrated in Changwon alone. A noteworthy point, as mentioned earlier in this section, is that the traffic volume between Changwon and Busan Metropolitan City accounts for only 0.3% of the total traffic to Busan. Most travelers instead use the route via Gimhae, passing through Changwon–Gimhae–Busan. As shown in the map in [Figure 6-2], this pattern appears to be driven by geographical constraints: Changwon’s eastern boundary is largely adjacent to Gimhae, and direct access to Busan is only possible through a relatively narrow southeastern corridor. Despite the possibility of direct travel to Busan, the low residential density in southeastern Changwon suggests that infrastructural limitations may discourage settlement in that area. Furthermore, although both Yangsan and Gimhae share substantial borders with Busan, traffic between Yangsan and Busan remains low, accounting for just 0.7% of the total. This highlights the need to investigate the causes behind the overwhelming concentration of traffic in the Gimhae–Busan corridor and to develop strategies for more effective traffic distribution. Additionally, although the relevant data was not publicly available for inclusion in the network analysis ([Figure 2]), it is confirmed that the Geoga Bridge (거가대교)[14] connects Geoje Island to Busan Metropolitan City. Given the dominant traffic volume through the Gimhae–Busan route, the bridge's current impact appears limited. However, over time, as population density shifts toward Geoje, the bridge may play a significant role in alleviating traffic imbalance. To support this shift, it is important to promote Geoje as a desirable residential area. Achieving a balanced distribution of traffic between Gyeongsangnam-do and Busan will also require broader collaboration with neighboring metropolitan municipalities. This would help decentralize the population currently concentrated near Busan and encourage more even regional development across the province.

The third factor helps explain cases where, despite the existence of multiple routes to neighboring metropolitan municipalities, one route becomes dominant due to geographical convenience—namely, extensive shared borders that naturally lead to traffic imbalance. Specific examples include Daegu Metropolitan City–Changnyeong-gun, Jeollabuk-do–Hamyang-gun, and Ulsan Metropolitan City–Yangsan-si. In the case of traffic between Gyeongsangnam-do and Gyeongsangbuk-do, it is useful to distinguish between the eastern corridor—adjacent to Miryang-si (61%) and Changnyeong-gun (16%)—and the western corridor—adjacent to Geochang-gun (18%) and Hapcheon-gun (4%). The high traffic volume between Gyeongsangbuk-do and Miryang-si can be attributed not only to geographical proximity but also to Miryang's adjacency to three densely populated cities, making it a natural conduit.
In contrast, Geochang-gun and Hapcheon-gun have similar population sizes (1.8% and 1.3% of Gyeongsangnam-do's population, respectively) and share comparable geographical conditions, such as similar border lengths with Gyeongsangbuk-do. Yet, the traffic volume differs by more than a factor of four. By tracing high-traffic segments near Geochang-gun in the network ([Figure 2]), it appears that Geochang serves—alongside Hamyang-gun—as a bridge between Jeollabuk-do and Gyeongsangbuk-do. On the other hand, Hapcheon-gun is situated between Geochang-gun, which borders both Jeollabuk-do and Gyeongsangbuk-do, and Changnyeong-gun, which connects to Gyeongsangbuk-do, Daegu Metropolitan City, and several densely populated areas of Gyeongsangnam-do. From a transportation perspective, Hapcheon-gun is relatively isolated, which likely contributes to its lower traffic volume.



[Figure 5] Percentage distribution of traffic volumes across different routes connecting Gyeongsangnam-do to its neighboring metropolitan municipalities. This visualization illustrates the degree of balance (or imbalance) in traffic flow among available paths to each adjacent region.



[Figure 6] (1) Proportion of each city and county's population relative to the total population of Gyeongsangnam-do, (2) Map of Gyeongsangnam-do. The image on the right is based on the "Status by City/County" map provided by the Gyeongsangnam-do Provincial Government website[15], with added labels for neighboring metropolitan municipalities and their shared boundaries.

As previously discussed, each node in the traffic-based network exhibits distinct characteristics across multiple dimensions. From this point forward, I will describe and quantify the features of each city and county node in Gyeongsangnam-do, as well as their interrelationships, using various metrics commonly employed in network theory. To begin, I calculated the degree centrality and strength of each node. In a network composed of a set of nodes V, where each node v \in V represents a city or county, these metrics are defined as follows:

$$D_i = \sum_{j}^{n} x_{ij} \qquad i, j \in N \quad \cdots\cdots\cdots \quad (1)$$

$$S_i = \sum_{j} w_{ij} \qquad i, j \in N \quad \cdots\cdots\cdots \quad (2)$$

In this context, the matrix elements $\{x_{ij}\}$ represent the adjacency matrix whose elements are either 1 or 0 depending on whether an edge directly connects node i and node j. The matrix elements $\{w_{ij}\}$, on the other hand, is a weighted adjacency matrix whose elements correspond to the traffic volume assigned to the edge between node i and node j. If no edge exists between two nodes, the value is set to 0. In the network shown in [Figure 2], the former matrix reflects the number of neighboring nodes, while the latter represents the total traffic volume exchanged with those neighbors. These two metrics were calculated and visualized in [Figure 7]. The number of neighbors ranges from a minimum of 2 (Namhae-gun) to a maximum of 9 (Changwon-si), with an average of 5 and a standard deviation of 1.67. Total traffic volume ranges from a minimum of 6,484 (Namhae-si) to a maximum of 6.01 million (Gimhae-si), with an average of 975,000 and a standard deviation of 1.457 million. To represent both variables on the same graph, the total traffic volume was normalized to a scale from 0 to 10. Following [Figure 7], [Figure 8] illustrates the distribution of these metrics. The near-normal distribution of neighbor counts suggests that, despite Gyeongsangnam-do’s geographical limitation of bordering the sea on one side, its administrative divisions have been efficiently designed to facilitate internal connectivity among cities and counties. However, as previously discussed, the particularly close relationship with Busan Metropolitan City and the resulting population concentration have led to traffic volumes being heavily skewed toward specific local municipalities. This imbalance appears to hinder the full utilization of the province’s otherwise well-structured network.

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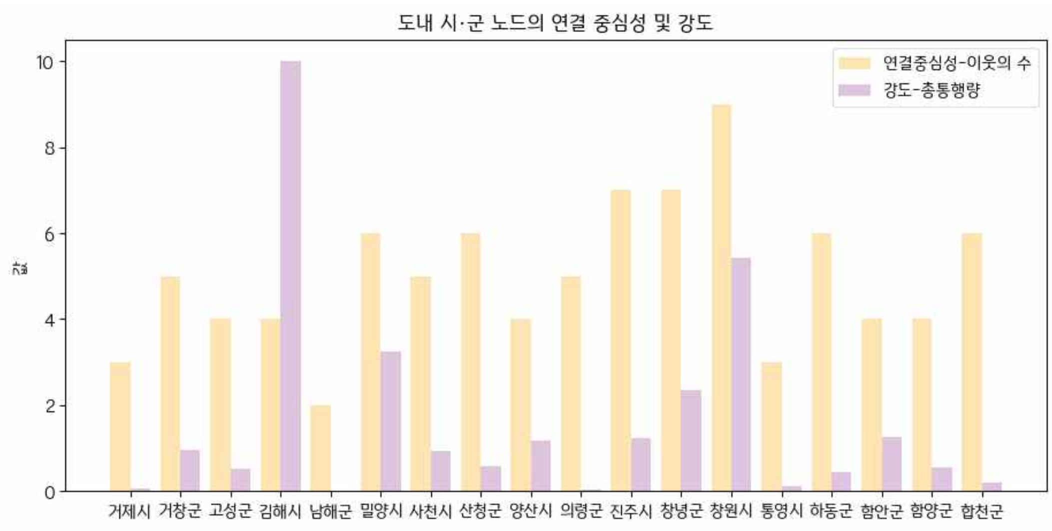
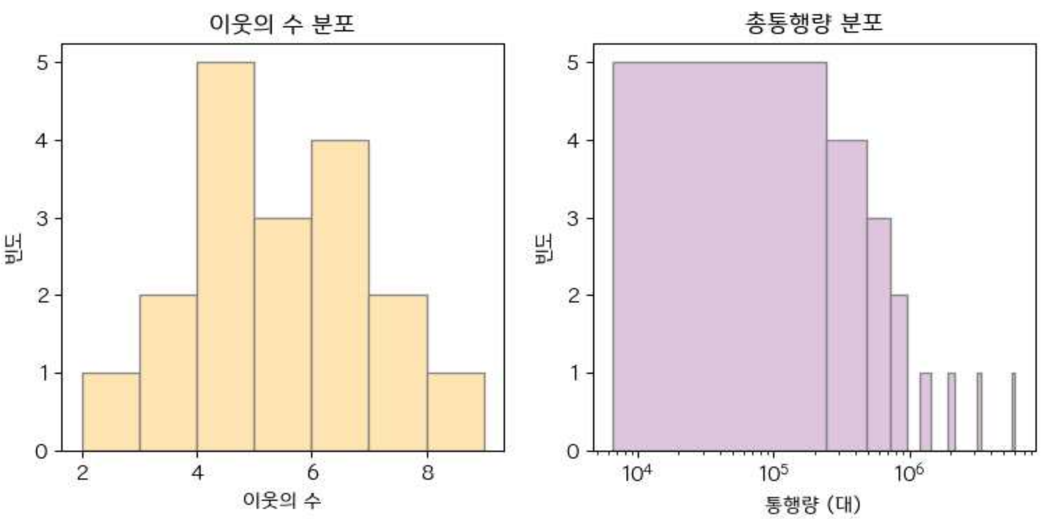


[Figure 7] Degree centrality and strength of city and county nodes within Gyeongsangnam-do. Degree centrality represents the number of neighboring nodes, while strength refers to the total traffic volume exchanged with those neighbors. The strength values have been normalized to a scale from 0 to 10 for comparative visualization.



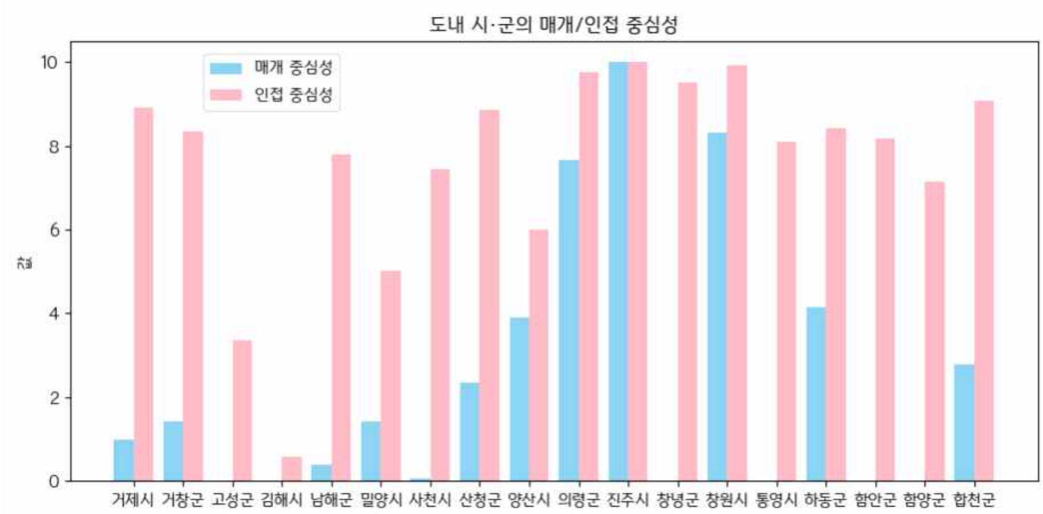
[Figure 8] (1) Distribution of the number of neighboring nodes for each city and county in Gyeongsangnam-do. (2) Distribution of total traffic volume exchanged with neighboring nodes. The near-normal distribution of neighbor counts suggests that the administrative divisions within the province have been efficiently designed to support smooth inter-regional connectivity, despite geographical constraints such as coastal boundaries.

Finally, as previously mentioned, I examined the betweenness centrality and closeness centrality of city and county nodes in Gyeongsangnam-do to identify which nodes may contribute to resolving the province's current road traffic challenges. In a network composed of a set of n nodes N, where each node i represents a city or county, these two centrality measures are defined as follows:

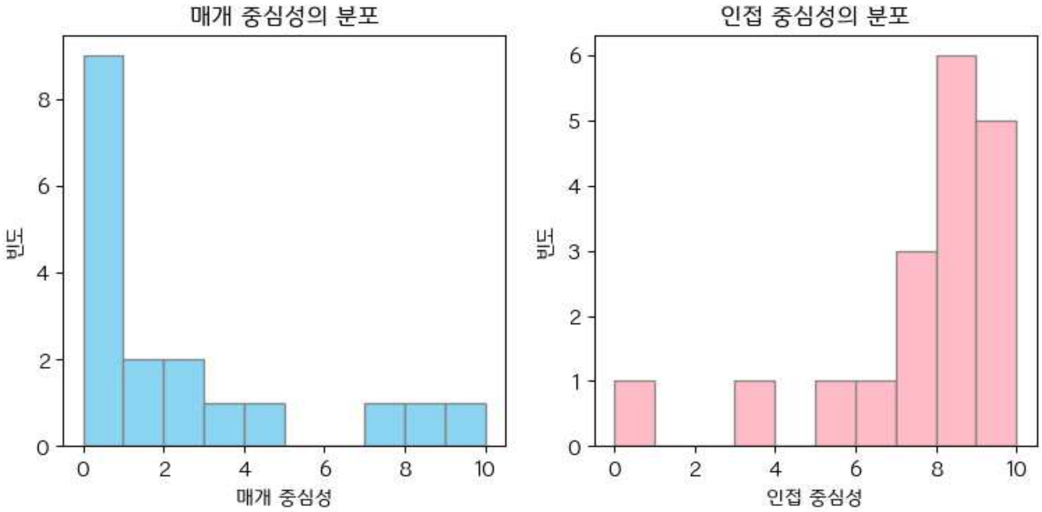
$$B_i = \sum_{g,h}^{n} \frac{\#(\sigma_{gh}(i))}{\#(\sigma_{gh})} \qquad i,j,g,h \in N \cdots\cdots\cdots\cdots\cdots\cdots \text{(3)}$$

$$C_i = \frac{1}{\sum_{j \in N-\{i\}}^{n} \sum_{g,h \in \sigma_{ij}}^{n} w_{gh}} \qquad i,j \in N \cdots\cdots\cdots\cdots\cdots\cdots \text{(4)}$$

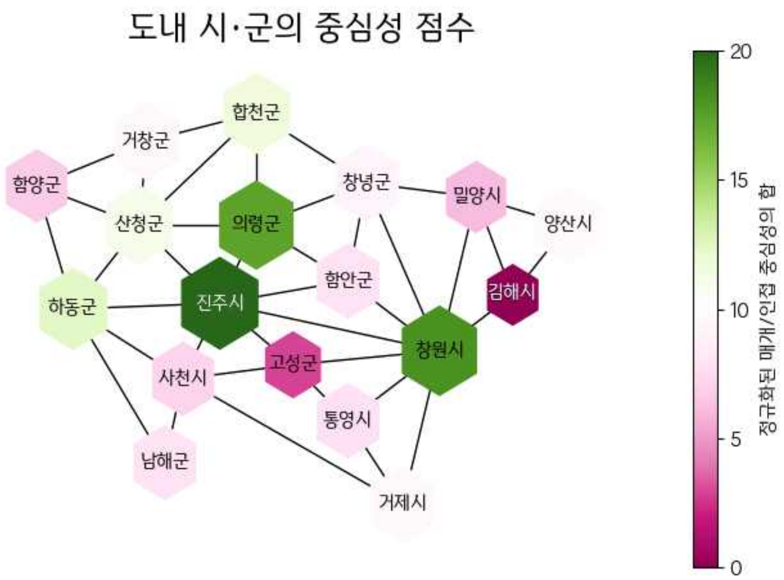
Here σ_{gh} refers to the shortest path from node g to node h, while $\sigma_{gh}(i)$ does to the shortest path from node g to node h via node i. $\{w_{ij}\}$, as defined above, represents the weighted adjacency matrix whose elements correspond to the traffic volume assigned to the edge connecting nodes i and j. Unlike in the earlier calculation of node strength, where traffic volume was treated as a positive attribute, here it is interpreted as a cost factor that may hinder smooth travel. In this framework, paths with lower traffic volumes are considered more efficient and are treated as shortest paths, under the assumption that they are less likely to experience congestion. (Ideally, travel speed or travel time would serve as more accurate cost indicators, but such data was only available for expressways, whereas traffic volume was the only accessible metric for other road types.) Within this framework, betweenness centrality measures the number of shortest paths between all node pairs in the network that pass through a given node. It quantifies how often a node serves as a bridge in inter-node travel. In contrast, closeness centrality is defined as the inverse of the sum of the shortest path distances from a given node to all other nodes. It reflects how efficiently a node can reach others in the network. Nodes that require travel through high-traffic routes (i.e., higher cost) will have lower closeness centrality. Using this approach, I calculated the betweenness and closeness centrality values for each city and county node in Gyeongsangnam-do. Their distributions are shown in [Figure 9] and [Figure 10]. Each centrality value was normalized to a scale from 0 to 10, consistent with the earlier degree and strength metrics. The sum of these two centrality measures was defined as the composite centrality score, which is visually represented by node color in [Figure 11].



[Figure 9] Distribution of betweenness and closeness centrality for city and county nodes within the province. Both centrality measures were normalized to a scale from 0 to 10 for comparability.



[Figure 10] The distributions of betweenness and closeness centrality exhibit distinct patterns. Many city and county nodes show low betweenness centrality but high closeness centrality, which can be attributed to the efficient administrative zoning and the concentration of traffic flows in specific areas, as previously illustrated in [Figure 8-1].



[Figure 11] Normalized composite centrality scores (0–10) combining betweenness and closeness. Jinju, Uiryeong, and Changwon emerge as key hubs with potential to ease traffic concentration—especially along the Changwon–Gimhae corridor.

The betweenness and closeness centrality values shown in [Figure 10] exhibit distinct distributions, each offering different interpretations. Betweenness centrality is generally low across most cities and counties, with only a few regions displaying high values. Areas such as Namhae-gun and Geoje-si, which have relatively few neighboring nodes (the average number of neighboring nodes was previously identified as five), or regions like Gimhae-si and Goseong-gun, which have many neighbors but experience high traffic volumes across all connecting edges, tend to show low betweenness centrality. In contrast, many cities and counties demonstrate high closeness centrality, which aligns with the normal distribution of neighboring node counts observed in [Figure 8-1]. This suggests that the province's administrative zoning has been effectively designed, facilitating smooth intra-provincial movement. In [Figure 11], three regions—Jinju-si, Uiryeong-gun, and Changwon-si—stand out with high composite centrality scores. These nodes not only have more neighbors than the average but also possess connecting routes that are expected to accommodate greater traffic volumes in the future, positioning them as potential transportation hubs. Among them, Changwon-si is particularly noteworthy, as it already handles substantial traffic volumes, as shown in [Figure 7]. Despite having the highest number of neighboring nodes, traffic is heavily concentrated on the route to Gimhae-si, leaving other edges underutilized. Therefore, promoting balanced regional development and encouraging the use of alternative routes connected to Changwon-si could help redistribute traffic more effectively. This would not only alleviate congestion but also enhance inter-city connectivity across Gyeongsangnam-do, leveraging its well-established network. On the other hand, Goseong-gun and Gimhae-si show notably low centrality scores. As previously mentioned, both regions face high traffic loads across all connected edges, indicating limited capacity to absorb additional traffic. Gimhae-si, in particular, records a low centrality score due to its relatively few neighboring nodes and the overwhelming traffic volumes on the Gimhae–Changwon and Gimhae–Busan corridors, as illustrated in [Figure 3]. The Gimhae–Busan route, confirmed in [Figure 4-2], experiences the most severe congestion during weekday morning commutes, with over ten million daily road users enduring significant delays. As such, it is urgent to disperse traffic through alternative routes leading into Busan Metropolitan City.

This study began by constructing a nationwide network of 17 metropolitan municipalities based on average weekday highway traffic volumes ([Figure 1]). Gyeongsangnam-do emerged as a key non-capital region, with the highest number of neighboring nodes (six) and the second-highest intercity traffic volume after the Seoul Capital Area—highlighting its role as a regional transportation hub. Expanding the scope, a more detailed network was built for Gyeongsangnam-do and its six adjacent regions, incorporating traffic data from national and local roads ([Figure 2]). Edge weights were assigned based on segment traffic volumes and visualized using a colormap, revealing strong connectivity with Busan Metropolitan City. By comparing traffic volumes with average commute-time speeds ([Figure 4]), the study assessed infrastructure performance. Notably, the Gyeongsangnam-do–Ulsan corridor showed severe congestion despite low traffic volume, suggesting the need to identify and address bottlenecks. An analysis of route balance across adjacent regions ([Figure 5]) revealed significant disparities. These imbalances were further examined using the constructed network, population data, and regional maps ([Figure 6]). Network theory was then applied to quantify the characteristics of city and county nodes within Gyeongsangnam-do. While the region's administrative layout supports efficient internal mobility, concentrated traffic flows—especially toward Busan—limit the full utilization of this advantage. Using betweenness and closeness centrality, a composite centrality score was calculated, identifying Jinju, Uiryeong, and Changwon as potential transportation hubs ([Figure 11]). Although these nodes have above-average connectivity, their links remain underutilized. Enhancing infrastructure around these areas could alleviate current traffic issues and improve accessibility for residents and visitors across the province.

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10) In network theory, an edge is also referred to as a link, or in Korean, 간선. Similarly, a network may be described as a graph or a complex system. Depending on whether the edges have directionality, networks are classified as either directed networks or undirected networks.
11) Category: Road routes in Gyeongsangnam-do, Wikipedia, https://ko.wikipedia.org/wiki/%EB%B6%84%EB%A5%98:%EA%B2%BD%EC%83%81%EB%82%A8%EB%8F%84%EC%9D%98_%EB%8F%84%EB%A1%9C_%EB%85%B8%EC%84%A0
12) This open API can be accessed by providing an authentication key along with the date and time zone. It returns information such as the date, time zone, rest area name, address, precipitation amount, and snowfall amount.
13) According to the "Highway Conzone and Lane-Type Traffic Flow Data (5-minute intervals)" provided by Korea Expressway Corporation via the National Transportation Data Open Market, a Conzone refers to a highway segment with consistent vehicle flow, typically encompassing interchanges (IC), junctions (JC), and tollgates (TG). https://www.bigdata-transportation.kr/frn/prdt/detail?prdtId=PRDTNUM_000000000007
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https://www.gyeongnam.go.kr/index.gyeong?menuCd=DOM_000000137004001000